

NASA FAR NAG10-225 UPN 334-20

UTEP Account #26-1203-90

Condensed

YEAR 2 FINAL REPORT

December 18, 2002

Principal Investigator: Rolando Quintana, Ph.D., P.E.

The University of Texas at El Paso

Department of Mechanical and Industrial Engineering

500 West University Drive

El Paso, Texas 79968-0521

1. TECHNICAL PROJECT DESCRIPTION

1.1.1 KSC - CHTFPM Application in High Pressure Gas Tank Testing Operation

Project Team:

- Bhupendra Deliwala, KSC
- Rolando Quintana, Ph.D. P.E.
- Daniel Diaz, Senior Industrial Engineering Student
- Flor Garcia, Senior Industrial Engineering Student
- Alvaro Rolando Orozco, Senior Industrial Engineering Student

On July 12, 2001, NASA launched space vehicle U.S. Shuttle Atlantis STS-104 with flight crew 7A aboard. The 7A crew will perform the first space walk from the Joint Airlock. The Joint Airlock will now enable crews to perform space walks in either United States or Russian spacesuits while recovering over 90 percent of the gases that were previously lost when airlocks were vented to the vacuum of space. The five-member crew of Shuttle Atlantis will also install two gaseous oxygen and two gaseous nitrogen storage tanks to the International Space Station, which will support future Station experiments and space walks (<http://www-pao.ksc.nasa.gov/shuttle/summaries/sts104/index.htm>).

These four high-pressure gas tanks, the basis of this study, were especially made by a private contractor and tested before being delivered to NASA Kennedy Space Center. In order to insure 100% reliability of each individual tank the staff at KSC decided to again submit the four tanks under more rigorous tests. These tests were conducted during a period from April 10 through May 8 at KSC. This application further validates the predictive safety model for accident prevention and system failure in the testing of four high-pressure gas tanks at Kennedy Space Center, called Continuous Hazard Tracking and Failure Prediction Methodology (CHTFPM).

It is apparent from the variety of barriers available for a hazard control that some barriers will be more successful than others in providing protection. In order to complete the Barrier Analysis of the system, a Task Analysis and a Biomechanical Study were performed to establish the relationship between the degree of biomechanical non-conformities and the anomalies found within the system on particular joints of the body. This relationship was possible to obtain by conducting a Regression Analysis to the previously generated data. From the information derived the body segment with the lowest percentage of non-conformities was the neck flexion with 46.7%.

Intense analysis of the system was conducted including Preliminary Hazard Analysis (PHA), Failure Mode and Effect Analysis (FMEA), and Barrier Analysis. These analyses resulted in the identification of occurrences of conditions, which may be becoming hazardous in the given system. These conditions, known as dendritics, may become hazards and could result in an accident, system malfunction, or unacceptable risk conditions. A total of 56 possible dendritics were identified.

Work sampling was performed to observe the occurrence each dendritic. The out of control points generated from a Weighted c control chart along with a Pareto analysis indicate that the dendritics "Personnel not Wearing Proper Protective and Hose/tubing located in high-traffic area" which account for 59.18% of total dendritic frequency need to be addressed to reduce the chance of a hazard from occurring. However, the occurrences of some dendritics are more important than others. As a result immediate, from a Weighted c perspective, corrective action should be taken to ameliorate the cause of the Class A dendritic "Personnel located under suspended or moving loads" rather than just the most commonly occurring dendritics. In any case the vast majority of data obtained indicates that testing operations possess a relatively high degree of safety.

1.1.2 Biomechanical Analysis and Prototype Redesign of the Hoisting Operation of 4 High Pressure Gas Tanks at KSC Based On CHTFPM Results

Project Team:

- Bhupendra Deliwala, KSC
- Rolando Quintana, Ph.D., P.E.
- Dense Dorado, Senior Industrial Engineering Student

- Javier Avalos, Senior Mechanical Engineering Student
- David Campos, Senior Mechanical Engineering Student

The hoisting operation involved in the preparation of High Pressure Gas Tanks (HPGT) is performed in the Operations and Checkout (O&C) building. This building has two 27.5 ton cranes that move payloads for the test and examination of the HPGTs. The HPGTs consist of two oxygen and two nitrogen High-Pressure Gas Tanks that will be attached externally to the airlock during two of the STS-104 space walks and will be transported to the space station attached to a Space Lab Double Pallet in the orbiter's cargo bay. These tanks provide a replenishable source of gas to the Atmosphere Control and Supply System (<http://www.spaceflight.nasa.gov/shuttle/archives/sts-104/cargo/>). The hoisting and lifting operation of the HPGTs is classified as a critical lifting, according to NASA standards. Given that the lifting and hoisting operation related to the HPGTs is critical, standards such as SAA01FS027-002 cover the 27.5 cranes used in the O&C building. Guidelines and standards for the hoisting process were created to avoid potential operational and occupational hazards.

The presence of hazards in the work environment may cause numerous accidents, which may lead to personal injuries or process and system failures; this is a result of a lack of safety. The purpose of this project was to apply a previously validated and reliable predictive safety model to prevent such accidents and system failures from occurring. The case of study in our case was the analysis of the preparation and hoisting of 4 high- pressure oxygen and nitrogen tanks at NASA's KSC.

The analysis was begun with the implementation of the Job analysis. With the job analysis the tasks needed to complete the entire hoisting operation were noted. For each operation, the limbs and joints used were also noted. This gave us an idea of where to focus the redesign. Once completed, the PHA was performed. Using the PHA, a brief idea of the possible hazards involved in each task was reported. The hazard cause and its effect on the human body itself were noted. If the PHA failed to detect any other hazards, the FMEA was of great importance. It was implemented taking the human body as a system within itself. Working from bottom-up approach, each major joint used in the operation was analyzed, and its affect on the rest of the system noted. For example if the wrist were to fail, what effect if any would this have on the rest of the system, i.e., the elbow. The various diseases and disorders involved in the working outside the nominal range of each joint were also noted. Lastly, the barrier analysis was implemented. It took into account the human machine aspect of the operation. With each possible hazard involved, certain controls were recommended. With the barrier analysis, it was clear that a redesign was needed. If a steel barrier was to be implemented to eliminate the hazard, this would prohibit the worker from performing his or her task. As an example, the worker must extend over the guard rail to unhook the gas tank from the hoist itself. A steel barrier would be to heighten the rail so as to prevent the worker from reaching too far. Obviously this would prohibit him or her from completing the task. An administrative barrier probably would not be followed either way. So the only solution was to redesign the hoisting operation.

NASA provided videotaped of the entire operation, which contained 30, 1.5 minute hoisting periods, which the NASA team digitized for the kinematical and kinetic analysis performed. The demerit scheme was mainly used to show the number of samples that were classified in the different nonconformities classifications. For the neck it was found that only 34% of the samples were done in the nominal range. The results for the shoulder point that only 10% of the samples worked in the permitted ROM. Elbow results shows that only 2% of the samples performed a task in the nominal range. For the wrist, none samples were found to be working in the permitted ROM, this is because the nominal ROM for the wrist is no movement at all. Therefore, since all samples were taken while performing a task, being the wrist part of the arm, the wrist had motion in all digitized samples. Finally, the L5/S1 disk had 68% of the samples working properly with respect of the neutral ranges of motion.

The ANOVA results show that the neck was the only body joint that presented statistical significance with respect of the hoisting operation anomalies. Therefore, the neck has greater risk of getting injured or holding an occupational illness, such as Induced Neck Stress. On the other hand the shoulder did not present any statistical significance with respect of the hoisting operation anomalies. Consequently, the shoulder is the only body joint that does not have risk of getting injured or with any probability of acquiring an occupational illness.

A new servicing palette was built with the goal of reducing biomechanical risks, as well staircase used in the operation. The final design (available in the Final Year report) was again put through a biomechanical analysis to determine if the design itself was true- from a safety analysis point of view. It was demonstrated that the redesigned

hoisting system (which was constructed in the laboratory using CREFORM and Work Smart) reduced dramatically the range of motion; therefore, the risk of musculoskeletal disorders will also decrease. The Final Report provides a detailed narrative on the analysis and the redesign.

1.1.3 A Biomechanical Framework for Predictive Safety at KSC

Project Team:

Bhupendra Deliwala, KSC

Rolando Quintana, Ph.D., P.E.

Analila Rojo, Industrial Engineering Graduate Student

Javier Avalos, Senior Mechanical Engineering Student

STS-104 Mission is one of NASA's latest 13-day missions launched on July 2001. The mission's purpose was to install, activate, and perform the first space walk from the Joint Airlock. The Airlock provides station-based Extravehicular Activity, or space walking, capability for both U.S. and Russian spacesuits. High-pressure gas assembly supports space walk operations and augments the Service Module gas re-supply system (NASA, 2001).

To verify and ensure the tanks' reliability and safety, KSC performed a series of inspections and tests on the four high-pressure gas tanks prior to servicing and launching mission STS-104. The hoisting operation of the service and testing of the HPGTs embody the basis of this study. The testing operations consist of fueling two tanks with oxygen and two with nitrogen. The tanks are then vented to assure all valves are 100%. Each high-pressure gas tank is later transported (hoisted), loaded, and attached to a Space Lab Double Pallet (SLDP). The hoist operation is rationalized as ideal for studying human-machine interfaces.

Most existing human motion methodologies are either complex and expensive or inconvenient to use in the field. The Biomechanical Framework for Predictive Safety provides sufficient supporting data to incorporate range of motion as a dendritic in the CHTFPM. This methodology is a proactive approach, to a desired level, to early detection of conditions (dendritics) leading to occupational disorders. The CHTFPM in conjunction with biomechanical analysis combines the underlying principles of specific areas of knowledge, namely system safety tools, ergonomic tools and videography. Motion measurement technology is utilized to capture anatomical landmark ranges of motion for biomechanical evaluation.

System safety tools and ergonomic tools provided results to evaluate the process from a biomechanical perspective relevant to occupational disorders. Job analysis is utilized to develop a task list of the hoisting operation. Preliminary hazard analysis identifies the hazardous state of the HPGT hoisting human-machine interface and assesses risk factors that were reasonably likely to cause or contribute to musculoskeletal disorders.

In this study the question of how out of range motions would affect the work system when conditions were tending to unsafe acts or possible occupational disorders was addressed. The biomechanical analysis was simplified to a reasonable approximation of reality of the HPGT operation rather than an approximation to a laboratory setting. The HPGT operation was analyzed through videography and human motion analysis technology. First, certain assumptions were stipulated. Some of these assumptions may appear to deviate from human motion measurement techniques, but as supporting data demonstrated the biomechanical framework forms an important building block in the advocated CHTFPM. In addition, literature divulged the implications with the use of markers or reflector in human motion measurement analysis. More important however, the results turned out to be major components in the construction of the biomechanical framework for predictive safety. In addition, the goal was not to develop a completely autonomous system but to provide predictive controls and range of motion tracking capabilities. This is essential for two reasons:

- Provide the ability to incorporate biomechanical factors not included in the underlying Continuous Hazard Tracking and Failure Prediction Methodology.
 - Cultivate the need to consider human-machine interaction from a system safety and ergonomics perspective.
- Occupational disorder and their relationship to working outside nominal range and lower yield and throughput were considered throughout the analysis of the HPGT hoisting operation. Job analysis, preliminary hazard analysis, failure mode and effect analysis, and barrier analysis provided valuable and significant information related to occupational hazards relevant to the HPGT operation.

The series of system safety and ergonomic tools aided in detecting potential detrimental musculoskeletal disorders. The Final Report contains related stick figure samples and corresponding pictures of the HPGT hoisting operation. These graphical samples and aforementioned analyses demonstrate how the human subject, in most instances, did not assume biomechanical efficient positions for the identified anatomical landmarks thus resulting in extreme postures and out of range movements.

Based on NASA's documents and identification of operational anomalies, working outside nominal ranges may affect system safety much like it does yield and throughput. The criticality of the process was directed towards the oxygen and nitrogen fuelled high-pressure-gas tanks during the hoisting operation where extreme or unsteady movements may lead to a potential harmful accident.

The essence of study was to determine if range of motion of anatomical landmarks could be used as a dendritic in a Predictive Safety framework. Specifically, if working outside the nominal range could be classified as a dendritic for predicting a systems problem, hazard or operational anomaly.

The aforementioned analyses, review of NASA's documentation, and range of motion data tend to support this concept. Although barrier analysis in the CHTFPM considers human-machine-environment interface, it did not account for potential musculoskeletal disorders imposed by this interface. The classification of range of motion as a dendritic in the CHTFPM would abstract the essence of predictive safety from an occupational standpoint. Consideration of nominal work envelopes would not only bring forward potential musculoskeletal disorders but the implications related to working outside nominal ranges. In summary, this study revealed the following:

- It is possible to obtain reliable and accurate joint flexion and extension range of motion measurements from field recorded video and motion measurement technology.
- This adaptable and relatively low cost method has the convenience of not imposing on the operators while providing essential information for continuous tracking and monitoring of system related hazards leading to accidents or injury.
- The results indicate the utility of video-based methods for measuring joint ROM in efforts to reduce the possibility of musculoskeletal disorders in the workplace.
- This approach to biomechanical analysis identifies in most cases critical exposures in a work situation. Data analysis supports this idea. Neck flexion and extension statistical analysis, demonstrates strong and consistent associations with neck induced stress. Appendix C illustrates raw data's graphical view of neck measurements near or beyond "very serious" severity levels. According to literature review, neck trauma beyond the superficial may result in injury to many vital structures.
- Statistical analysis illustrates a relationship between angle displacement of the neck and operational anomalies with respect to the saggital plane.
- Results of system safety analysis and identification of operational anomalies demonstrate the need to incorporate biomechanics to the CHTFPM, thus classifying range of motion as a dendritic.
- Literature review unveiled that out of range postures negatively impact the human system. When extreme postures are assumed, the available body segment strength decreases and accelerates muscle fatigue. Fatigued muscles are more prone to injury and reduced performance.
- Although the biomechanical analysis was restricted to measurement of range of motion of defined joints, literature exposed the physiological aspects of working outside the nominal work envelope. Extreme postures define by range of motion or joint angle measurements were found to impose stress to the muscles thus reducing work efficiencies and onset of pain and fatigue.
- Data also demonstrate, considering previously stated limitations, the need for further biomechanical evaluation.
- 2-D biomechanical analysis provides means to analyze range of motion in the saggital plane as a sequence of static postures.
- Based on biomechanical study in the saggital plane, joint displacement can be considered a dendritic in the CHTFPM.